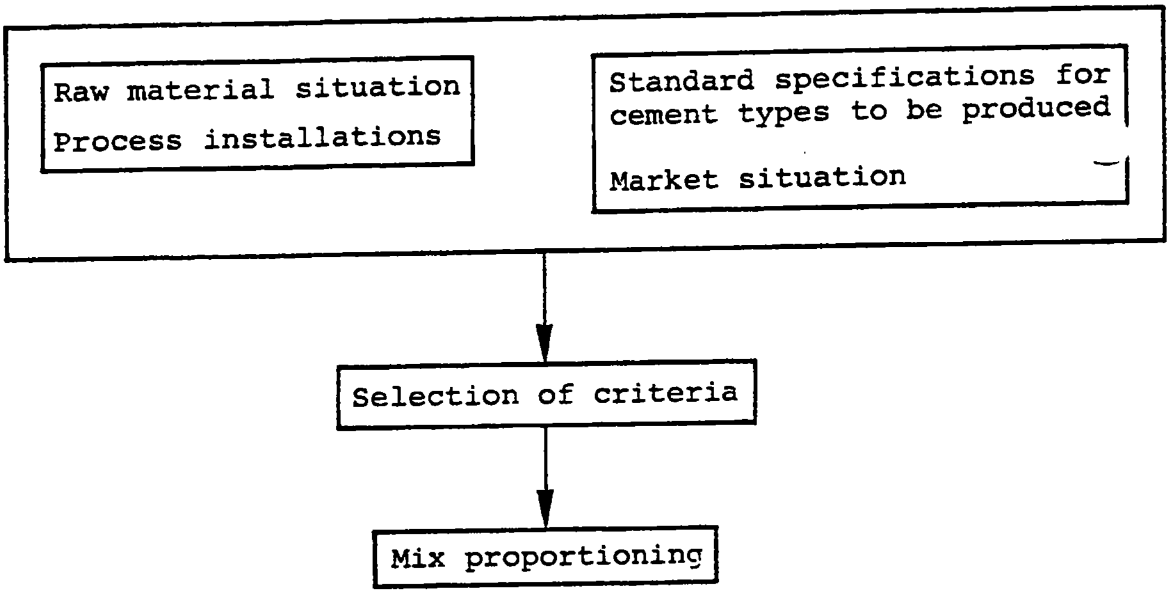
MIX DESIGN

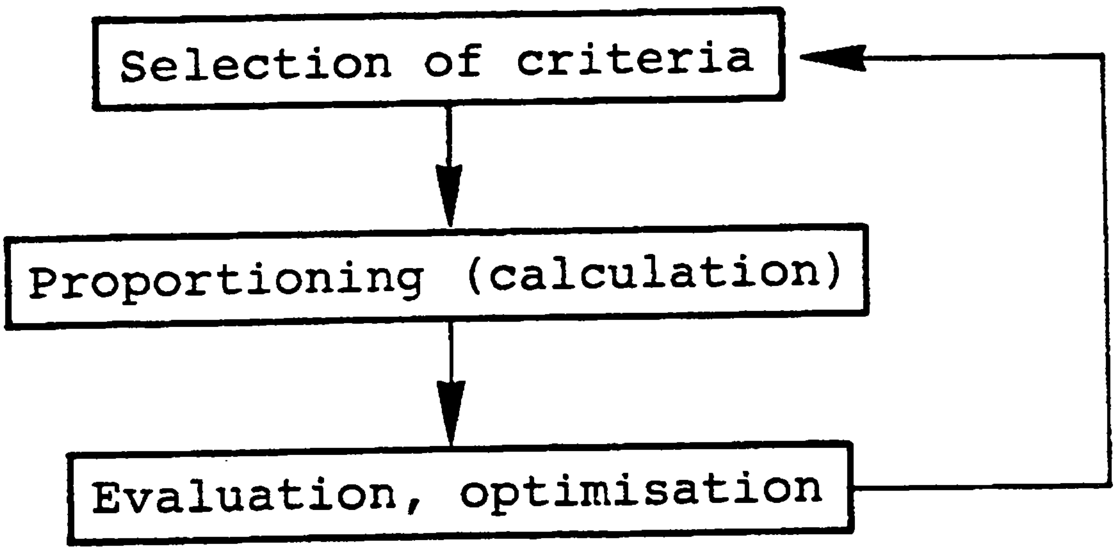
1. GENERAL

A raw mix design comprises not only raw mix proportioning but also considerations of such factors as standard specifications of the cement types to be produced, the market situation and the available process installations.



The selection of criteria is dictated by the standard specifications.

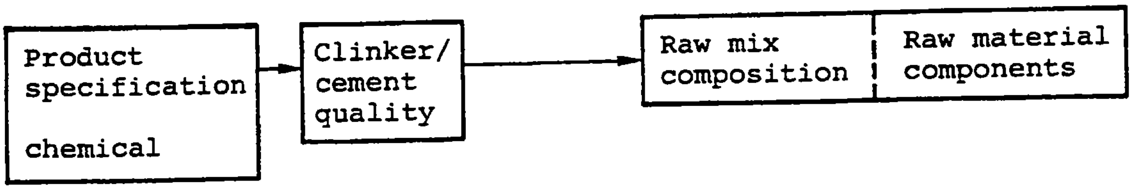
Designing raw mixes does not only involve the proportioning (calculation) but includes an evaluation of the obtained results. The latter involves optimisation with respect to costs and materials.



2. DEFINITION OF CRITERIA FOR MIX CALCULATION

Any type of cement has to conform to the individual cement standards of a particular country. Standards (standard specifications) normally include chemical specifications for clinker and cement. Together with the physical and strength requirements, they guarantee a suitable quality potential for the respective cement type.

With regard to the raw material aspects only the chemical requirements are significant:



In other words: the product specifications dictate the clinker/cement quality which in turn dictates the chemical composition of the raw mix and finally the selection of the raw material components.

The above sequence can also be reversed: an existing raw material configuration with little freedom as to the proportioning of the raw mix, may permit the manufacture of only one particular type of clinker.

Table 41 Influence of chemical requirements on raw materials

Chemical requirements	Influence on raw material
min. SO_3	Rejection of SO_3-bearing components (e.g.) gypsum-containing shale)
min. MgO	Rejection of MgO-bearing components (e.g. dolomitic limestone)
min. Alkali	Selection of raw material with low alkali-content
min. C_3A	Selection of components with very low alumina content and / or high iron content

Table 41 shows the influence of chemical requirements on the choice of raw materials.

The following chemical criteria are normally used as a basis for raw mix proportioning (Table 42; on clinker basis):

Table 42 Chemical criteria for raw mix proportioning

criteria	"normal" range limit (for clinker)	formulas, remarks
MgO	max. 5% (6%)	for all cements
SO_3*	3 - 4,5%	depending on cement type
LIME STANDARD or LIME SATURATION FACTOR	0,9 - 1 or 90 - 100%	$\frac{CaO}{2,8\ SiO_2 + 1,2\ Al_2O_3 + 0,65\ Fe_2O_3}$
"Improved" Lime standard **	90 - 100%	$\frac{100\ (CaO + 0,75\ MgO)\ **}{2,80\ SiO_2 + 1,18\ Al_2O_3 + 0,65\ Fe_2O_3}$
Index of activity	2,5 - 3,5	$\frac{SiO_2}{Al_2O_3}$
Hydraulic ratio	2,0 - 2,4	$\frac{CaO}{SiO_2 + Al_2O_3 + Fe_2O_3}$
SILICA RATIO	1,8 - 3,4	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$
ALUMINA RATIO	1,5 - 2,5 (0,7 - 3,5)	$\frac{Al_2O_3}{Fe_2O_3}$
Total alkali	< 0,6%	$Na_2O + 0,66\ K_2O$ for low alkali clinker
C_3S	50 - 60%	except for ASTM type IV
C_3A	max. 3% BS max. 5% ASTM	for sulfate-resisting cement

* for cement ** 100 (CaO + 1,5) for MgO < 2%

The proportioning of raw mixes for ordinary Portland cement is mostly based on the following specific criteria:

- MgO
- Lime standard or lime or saturation factor (or C_3S)
- Silica ratio
- Alumina ratio

As Table 42 indicates, ratios are the preferred chemical criteria for proportioning since they offer the advantage of expressing the main and most important chemical parameters such as SiO_2, Al_2O_3, Fe_2O_3 and CaO in one single figure.

Other important criteria such as type and composition of fuels should not be overlooked. Coal ash as a combustion product of coal, for instance, has to be analysed quantitatively and qualitatively and should be treated as an individual raw material component. Fuel oil has to be considered as a potential carrier of sulphur, etc.

Additional criteria which could have bearing on the mix proportioning refer to performance characteristics, e.g.:

- minimum dust emission
- burnability and coating properties
- extreme components which affect machine performance

or to economic factors, e.g.:

- maximum overall economy
- easy and simple operations
- minimum number of components

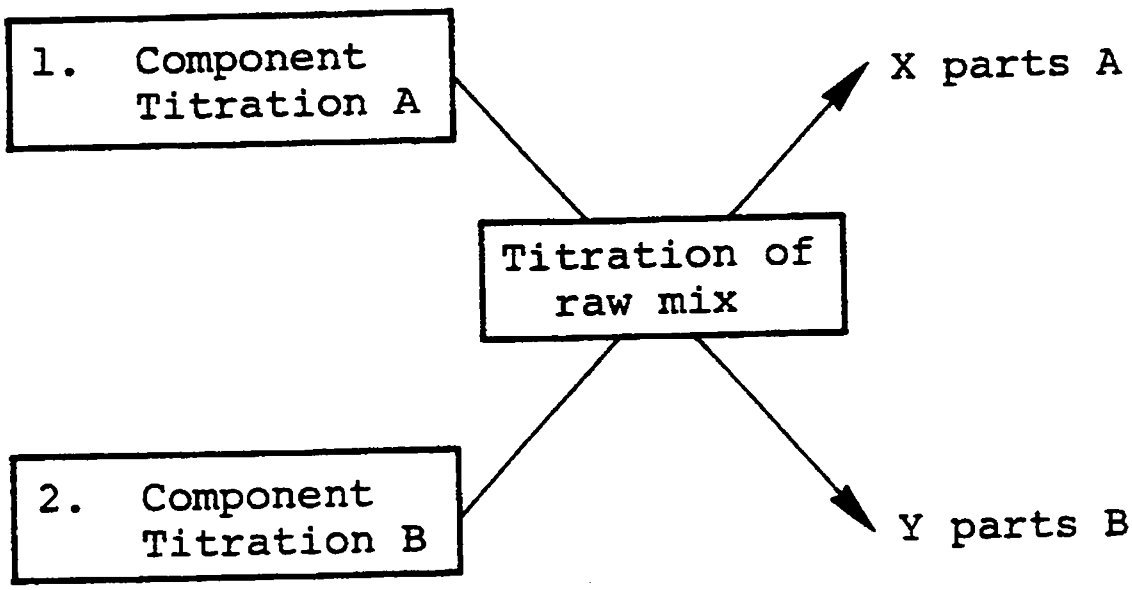
However, performance characteristics in particular can normally be controlled regarding the "normal" chemical requirements for cement raw mixes. The economic factors, on the other hand, are of the same significance as the chemical requirements.

3. PRINCIPLES AND METHODS OF MIX PROPORTIONING

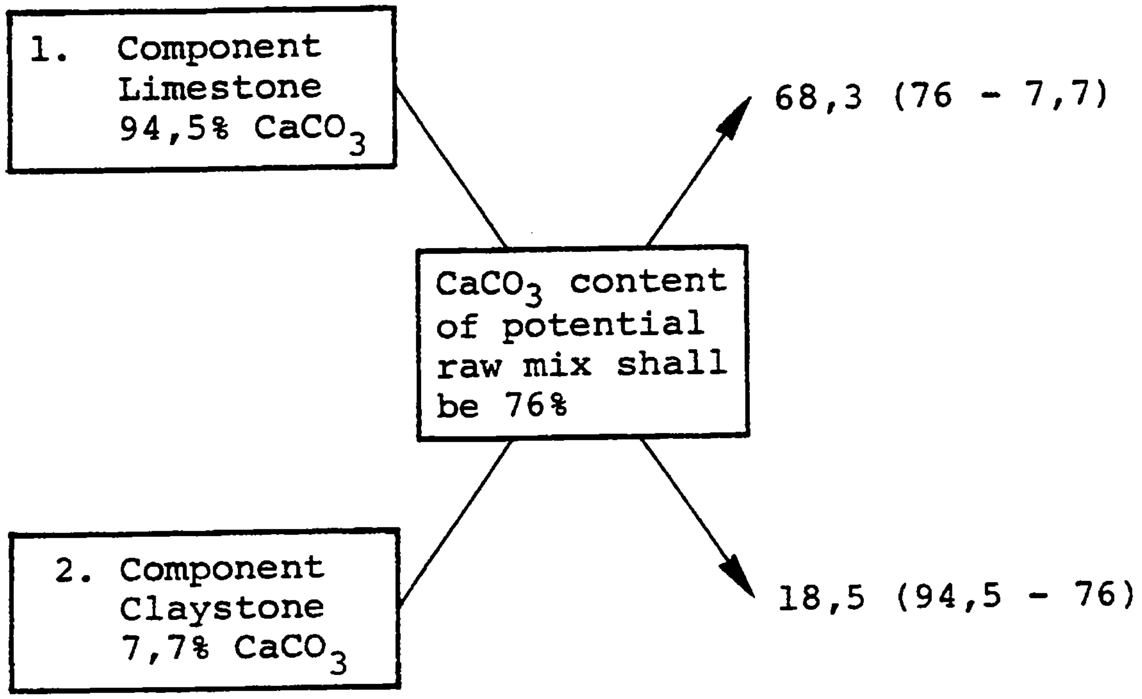
Proportioning (calculation) of potential cement raw mixes can be accomplished by various methods:

3.1 X-Pattern

The x-pattern represents a linear estimation of two raw material components by selecting the anticipated titration value (total carbonate content) of the potential raw mix as basis.



or as a numerical example.



The potential raw mix with a titration value of 76% would thus consist of:

$$\frac{\text{limestone}}{\text{claystone}} = \frac{68.3}{18.5} = \frac{3.69}{1}$$

or

limestone 78,6 % claystone 21,3 %

The resulting analysis of the raw mix has to be checked with regard to the requirements of the standard specifications.

3.2 Manual Calculation

There are a number of mathematical methods for two and three-component systems. Formulas are not complicated but comprise a large number of steps. The method of manual calculation as such is outdated.

3.3 Graphical Methods

These methods require preparatory work (manual calculations) for the determination of the relevant figures which are the basis for the construction of the diagrams and graphs. Graphical methods represent a rather archaic stage of mix proportioning.

3.4 Programmable Calculator

Programmable calculators normally produce one solution (out of possibly several). Obviously, this method is the best way to obtain a quick solution.

3.5 Computer Optimisation

It provides the optimum of a series of possible solutions considering the price factors as variables. If the available raw materials cannot meet the specified requirements for the raw mix, an approximate and an exact solution considering the missing constituents are produced (Tables 43 - 47).

Note: Mix calculations are normally based on dry raw materials. In practice, the natural moisture contents of the raw material components have to be considered too. This may entail alterations of the original mix proportions.

Table 43

19942222 GLADSTONE

A N A L Y S E N

KOMPONENTEN	GVER	SIO2	AL2O3	FE2O3	CAO	MGO	K2O	NA2O	REST	CAOFREI	SO3	PREIS
CALLIDE COAL	0	46.17	37.81	11.34	1.88	1.55	.40	.35	.58	0	0	1.00E 06
LIME 7734	43.29	1.40	.45	.29	54.09	.49	.02	.02	.35	0	0	1.00E 00
OVBURD 7733	13.92	48.30	17.50	12.20	4.18	.59	.14	.58	2.73	0	0	1.00E 00
SAND	.71	94.80	2.88	.24	.35	.13	1.29	.20	0	0	0	1.00E 03
CINDERS	1.43	25.58	3.30	66.70	1.28	1.44	.24	.17	.08	0	0	1.00E 04

A N F O R D E R U N G E N

	OBERE GRENZE	UNT. GRENZE	RESULTAT
MGO	100.000		.812
NA2O+0.658K2O	100.000		.283
AL2O3	100.000		5.804
FE2O3	100.000		4.959
SIO2		0	21.794
KALKSTANDARD	1003.350	-0.650	92.353
TONERDE-MODUL	100.325	-0.825	1.170
SILIKAT-MODUL	2.025	1.975	2.025
C3S	55.530	54.500	55.500
C2S		-100.000	20.639
C3A	7.300		7.000
C4AF+2C3A	200.300		29.074
KOMPONENTE 1	.025	.024	

R E S U L T A T E

MISCHUNGSVERHAELTNIS

CALLIDE COAL	.0245
LIME 7734	.7743
OVBURD 7733	.1292
SAND	.0553
CINDERS	.0167
TOTAL	1.0000

KLINKER-ANALYSE

C3S	55.5090
C2S	20.6391
C3A	7.0000
C4AF	15.0740
MGO	.8121
ALKALI	.3449
CAOFREI	0
TONERDEMODUL	1.1705
SILIKATMODUL	2.0240
KALKSTANDARD	92.3526
SIO2	21.7937
AL2O3	5.8036
FE2O3	4.9586
CAO	65.6571
MGO	.8121
K2O	.1803
NA2O	.1586
HYDR. MODUL	2.0147
GIPS	0
PREIS	2.23001E 02

Table 44

2064 05050-044 MIXES ILIGAN NR 4 — 28. 6. 77 OPTIMIERUNG

A N A L Y S E N

NR	GVER	SIO2	AL203	FE203	CAO	MGO	K2O	NA2O	TIO	CRO	MNO	SO3	P2O	CL	F	REST	PREIS
1	4290	190	68	39	5290	42	4	4	3	0	8	8	4	1	0	45	.10+00
2	1925	4150	1207	598	1576	·239	99	109	52	0	8	9	11	9	0	0	.10+00
3	839	6380	1329	400	340	92	219	250	44	0	6	9	8	11	0	68	.22+00
4	293	1477	287	7297	247	53	40	31	55	0	2	141	0	0	0	65	.59+00

A N F O R D E R U N G E N — R E S U L T A T E

	MAX.	MIN.	RRESULTAT	MISCHUNGSVERHAELTNIS		KLINKERANALYSE	
MGO	100.000	.000	1.145	LIMESTONE	.7535	C3S	59.5000
NA2O+.658K2O	100.000	.000	1.143	SHALE LOW	.1262	C2S	17.8631
AL2O3	100.000	.000	5.575	SHALE HIGH	.1145	C3A	9.6675
FE2O3	100.000	.000	3.022	PYRITE CIND	.0059	C4AF	9.1863
SIO2	100.000	.000	21.880		.0000	MGO	1.1453
KALKSTANDARD	1000.050	-.050	94.179		.0000	ALKALI	1.3610
TONERDEMODUL	1.845	1.795	1.845		.0000	HYDR. MODUL	2.1371
SILIKATMODUL	2.595	2.545	2.545		.0000	TONERDEMODUL	1.8450
C3S	60.500	59.500	59.500		.0000	SILIKATMODUL	2.5450
C2S	100.000	-100.000	17.865		.0000	KALKSTANDARD	94.1791
C3A	100.000	.000	9.669		.0000	SIO2	21.8795
C4AF+2C3A	200.000	-100.000	28.521	********************		AL2O3	5.5753
KOMPON. 1	1.000	.000	.753	T O T A L	1.0000	FE2O3	3.0218
						CAO	65.7423
						MGO	1.1453
OPTIMUM				PREIS	.11874+00	K2O	.6395
						NA2O	.7225
						TIO2	.2242
						CR2O3	.0000
						MN2O3	.1224
						SO3	.1441
						P2O5	.0864
						CL	.0509
						F	.0000
						REST	.6582

Table 45

OPTIMALISIERUNG

2052 05850,044 MIXES ILIGAN NO. 1

ANALYSEN

KOMPONENTEN	GVER	SIO2	AL2O3	FE2O3	CAO	MGO	K2O	NA2O	REST	CAOFREI	SO3	PREIS
LIMESTONE	42,90	1,90	,69	,40	52,90	,43	,04	,05	,69	0	0	1,40E 01
SHALE LOW	19,30	41,60	12,10	6,00	15,00	2,40	1,00	1,10	,70	0	0	1,40E 01
SHALE HIGH	8,40	63,80	13,30	4,00	3,40	,93	2,20	2,50	1,47	0	0	2,10E 01
PYRITE CIND	2,90	14,90	2,90	73,60	2,50	,59	,41	,32	1,02	0	0	5,41E 01
SILICA SAND	3,50	89,30	2,50	2,10	1,00	,28	,02	,08	,42	0	0	5,05E 01

ANFORDERUNGEN

	OBERE GRENZE	UNT. GRENZE	RESULTAT
MGO	100,000		1.251
NA2O+0,658K2O	100.000		.632
AL2O3	100.000		4.666
FE2O3	100.000		3.009
SIO2		0	21.821
KALKSTANDARD	1000.050	-1.050	96.437
TONERDE-MODUL	1.225	1.175	1.225
SILIKAT-MODUL	2.625	2.575	2.575
C3S	68.500	67.500	68.500
C2S		-100.000	10.909
C3A	100.000		5.927
C4AF+2C3A	200.000		23.433
KOMPONENTE 1	1.000	0	

RESULTATE

MISCHUNGSVERHAELTNIS	
LIMESTONE	,7472
SHALE LOW	,1912
SHALE HIGH	0
PYRITE CIND	,0121
SILICA SAND	,0495
TOTAL	1,0000

KLINKER-ANALYSE	
C3S	68,5090
C2S	10,9092
C3A	5,9272
C4AF	11,5783
MGO	1,2510
ALKALI	,7533
CAOFREI	0
TONERDEMODUL	1,2250
SILIKATMODUL	2,5750
KALKSTANDARD	96,4373
SIO2	21,0212
AL2O3	4,6656
FE2O3	3,0097
CAO	66,6193
MGO	1,2510
K2O	,3545
NA2O	,3920
HYDR. MODUL	2,1990
GIPS	0
PREIS	1,25620E 01

Table 46

OPTIMALISIERUNG

2057 05050,044 MIXES ILIGAN NO. 7

A N A L Y S E N

KOMPONENTEN	OVER	SIO2	AL2O3	FE2O3	CAO	MGO	K2O	NA2O	REST	CAOFREI	SO3	PREIS
LIMESTONE	42,90	1,90	,69	,40	52,90	,43	,04	,05	,69	0	0	1,00E 01
SHALE LOW	19,33	41,60	12,10	6,80	15,80	3,40	1,80	1,10	,78	0	0	1,00E 01
SHALE HIGH	8,40	63,80	13,30	4,00	3,40	,93	2,20	2,50	1,47	0	0	2,10E 01
PYRITE CIND	2,96	14,90	2,90	73,60	2,50	,59	,41	,32	1,82	0	0	5,01E 01
SILICA SAND	3,50	89,30	2,50	2,10	1,80	,28	,02	,08	,42	0	0	5,05E 01

A N F O R D E R U N G E N

	OBERE GRENZE	UNT. GRENZE	RESULTAT
MGO	100.000		1.488
NA2O+0,658K2O	100.000		.821
AL2O3	100.000		5.074
FE2O3	100.000		3.218
SIO2		0	21.593
KALKSTANDARD	1000.050	-0.050	94.654
TONERDE-MODUL	1.825	1.775	1.825
SILIKAT-MODUL	2.425	2.375	2.375
C3S	60.500	59.500	59.500
C2S		-100.000	17.945
C3A	100.000		10.120
C4AF+2C3A	200.000		30.036
KOMPONENTE 1	1.000	0	

R E S U L T A T E

MISCHUNGSVERHAELTNIS	
LIMESTONE	,7163
SHALE LOW	,2665
SHALE HIGH	0
PYRITE CIND	,0020
SILICA SAND	,0152
TOTAL	1,0000

KLINKER-ANALYSE	
C3S	59,5000
C2S	17,0454
C3A	10,1259
C4AF	9,7839
MGO	1,4877
ALKALI	,9789
CAOFREI	0
TONERDEMODUL	1,8250
SILIKATMODUL	2,3750
KALKSTANDARD	94,6540
SIO2	21,5934
AL2O3	5,0736
FE2O3	3,2184
CAO	65,7698
MGO	1,4877
K2O	,4625
NA2O	,5164
HYDR. MODUL	2,1434
GIPS	0

Table 47

2066 05050-044 MIXES ILIGAN NR 11 — 28. 6. 77 OPTIMIERUNG

ANALYSEN

NR	GVER	SIO2	AL2O3	FE2O3	CAO	MGO	K2O	NA2O	TIO	CRO	MNO	SO3	P2O	CL	F	REST	PREIS
1	4290	190	68	39	5290	42	4	4	3	0	8	8	4	1	0	45	.10+00
2	1925	4150	1207	598	1576	239	99	109	52	0	8	9	11	9	0	0	.10+00
3	839	6380	1329	400	340	92	219	250	44	0	6	9	8	11	0	68	.22+00
4	293	1477	287	7297	247	53	40	31	55	0	2	141	0	0	0	65	.58+00

ANFORDERUNGEN — RESULTATE

	MAX.	MIN.	RRESULTAT
MGO	100.000	.000	1.362
NA2O+.658K2O	100.000	.000	1.010
AL2O3	100.000	.000	5.933
FE2O3	100.000	.000	3.216
SIO2	100.000	.000	21.453
KALKSTANDARD	1000.050	-.050	94.860
TONERDEMODUL	1.845	1.795	1.845
SILIKATMODUL	2.395	2.345	2.345
C3S	60.500	59.500	59.500
C2S	100.000	-100.000	16.642
C3A	100.000	.000	10.287
C4AF+2C3A	200.000	-100.000	30.350
KOMPON. 1	1.000	.000	.729

MISCHUNGSVERHAELTNIS	
LIMESTONE	.7290
SHALE LOW	.2116
SHALE HIGH	.0555
PYRITE CIND	.0039
	.0000
	.0000
	.0000
	.0000
	.0000
	.0000
	.0000
********************	
T O T A L	1.0000

KLINKERANALYSE	
C3S	59.5000
C2S	16.6421
C3A	10.2874
C4AF	9.7754
MGO	1.3622
ALKALI	1.2040
HYDR. MODUL	2.1438
TONERDEMODUL	1.8450
SILIKATMODUL	2.3450
KALKSTANDARD	94.8600
SIO2	21.4528
AL2O3	5.9327
FE2O3	3.2156
CAO	65.6038
MGO	1.3622
K2O	.5672
NA2O	.6368
TIO2	.2507
CR2O3	.0000
MN2O3	.1259
SO3	.1410
P2O5	.0927
CL	.0538
F	.0000
REST	.57699

OPTIMUM — PREIS .11111+00

4. PRINCIPLES OF RAW MIX ASSESSMENT

Basically, evaluation and assessment of raw material components (4.4) and raw mixes refer to the same principles. The only difference exists in the immediate comparison of the chemical composition of a raw mix with the standard specifications of the products for which it is intended.

4.1 Mix Type

The possible combinations of different rocks used in raw mixes can be classified as mix types. Important varieties are:

- Argillaceous limestone (marl) having the composition of a natural cement. An optimum homogenisation is realised in the rack texture itself. The reactions can easily take place even with a coarsely grained raw mix.
- The same rock in a metamorphic condition contains well crystallised silicates instead of clay minerals. Under otherwise similar conditions, the reactivity is lower than in the first case and there is a high probability that dust formation will occur in the preparation and burning process.
- Contrary to the above cases is the combination of pure limestone with pure clay. To get a close contact between lime and silicate, both components have to be ground finely and homogenised intensively. Depending on the type of clay minerals, the mixes can be more or less reactive,
- A further mix type is the combination of relatively pure limestone, argillaceous limestone and sandstone. Quartz introduced by the sandstone will decrease the grindability and the burnability to some extent. Problems may occur when less reactive minerals are present in the other two components.

Rock combinations actually used can easily be related to this series of mix types. The situation becomes more complicated when additions like pyrite ash, iron ore or bauxite are used.

4.2 Comparison of Raw Mix with Standard Specifications

Any raw mix composition has to be compared with the locally applied standard specifications in order to evaluate potential conformity. As an example, Table 48 compares two analyses of typical Portland cements with the ASTM-specifications for the five main types of Portland cement, whereby these types are designated as follows:

Type I	Ordinary Portland cement
Type II	Moderate sulphate resistance or moderate heat of hydration
Type III	High early strength
Type IV	Low heat of hydration
Type V	High sulphate resistance

Table 48 Raw mix composition and specification.

	clinker composition		chemical requirements according to ASTM specifications for type:				
	I	II	I	II	III	IV	V
Loss on ignition	0.43	0.69	<3.0	<3.0	<3.0	<2.5	<3.0
SiO_2	20.8	22.8		>21.0			
Al_2O_3	6.0	3.8		<6.0			
Fe_2O_3	2.5	4.4		<6.0			
CaO	66.7	65.2					
MgO	1.4	2.2	<6.0	<6.0	<6.0	<6.0	<6.0
So_3 *	0.52	0.16	<3.0 <3.5	<3.0	<3.5 <4.0	<2.3	<2.3
K_2O	0.80	0.39					
NA_2O	0.20	0.30					
Mn_2O_3	0.50	0.05					
P_2O_5	0.16	0.07					
TiO_2	0.27	0.26					
Cl	0.01	0.01					
Total	99.84	100.33					
Silica ratio	2.4	2.9					
Alumina ratio	2.4	0.9					
Lime saturation	99.6	93.4					
C_3S	59.9	65.1			<35		
C_2S	14.4	16.2			>40		
C_3A	11.7	2.8		<8	<15	<7	<5
C_4AF	7.6	12.7					<20 **

* depending on C_3A content ** $C_4AF + 2\ C_3A$

It is obvious in Table 48 that mix I conforms to the specifications for type I (ordinary Portland cement) and type III (high early strength), but not for the other types.

Mix II conforms to all cement types except type IV (low heat of hydration).

If a composition of a potential raw mix does not meet the specifications for a particular type of cement, the following measures have to be weighed:

- Modification of proportioning criteria (lime saturation factor, silica ratio, C_3A- or Al_2O_3 content, etc.)
- Selection of necessary corrective materials (silica sand, etc.)
- Replacement of components (replacement of an alumina rich claystone by a silica-rich material for production of ASTM type IV and V cements, etc.)
- Replacement of the selected fuel type or fuel quality (coal with little ash instead of coal with a high ash content, if the coal ash composition becomes a critically influencing parameter, etc.)

Influence of minor ("deleterious") elements

The main influencing effect of the so-called deleterious constituents or elements on preparation and production is discussed in chapter 4.4.2. The following deals only with limits and effects of these constituents in the cement raw mix. Under normal circumstances, the following ranges and limits are to be expected:

Table 49 Deleterious constituents in cement raw mixes

deleterious constituents	"normal" range % (clinker basis)	limits % (clinker basis)	remarks
Alkalis:			
K_2O	0,5 - 0,8	0,6	for low-alkali
Na_2O	0,2 - 0,4	as Na_2O	clinker
MgO	1 - 3	5 - 6	according to local specifications
SO_3	0,2 - 1,0	1 - 1,5	higher SO_3 in clinker reduces quantity of gypsum to be added
P_2O_5	0,0 .. - 0,3	0,5 - 0,8	
Cl	0,01 - 0,03 (0,01 - 0,1)		depending on and determining the process
F	0,01 - 0,1		air pollution
Cr_2O_3	0,01 - 0,04		dermatitis
Fe_2O_3	3 - 5	0,3	for white cement production

These limits should not be regarded as isolated figures but rather as part of a multi-component system (including contributions from the fuel). Particular attention should be given to the systems of:

K_2O ----- Na_2O ----- SO_3

K_2O ----- Na_2O ----- Cl

whereby an effort should be made to achieve equalised alkali sulphur balance in order to prevent problems in the kiln system.

Only a few deleterious constituents are limited by specifications, e.g. the MgO and the total alkali-content (for low-alkali clinker). The others are not specified (limited) but practical experience with processing and quality requirements of the product (clinker/cement) dictate their quantitative limits.

4.3 Assessment of the Mineralogical Composition of Cement Raw Mixes.

A routinely performed assessment of a raw mix includes as a very important part the examination of the mineralogical composition (Table 50).

Table 50 Mineralogical assessment of raw mix

Minerals	Effects on technology
Aragonite ($CaCO_3$)	dry grinding → coating in the mill and high power consumption
Quartz (SiO_2)	grinding → abrasion, wear and high power consumption burning → impairs burnability
Feldspar	burning → impairs burnability, low reactivity
Clay minerals: Montmorillonite Illite Kaolinite Chlorite Mica Palygorskite	preparation → water absorption, stickiness burning → improved burnability dust production → reduced dust prod. coating properties → facilitates coating
Minerals of good crystallinity	reactivity low, require more energy for transformation
Minerals of low crystallinity	reactivity high, less energy necessary for transformation

4.4 Assessment of Raw Mixes with regard to Cement Production and Choice of Process

As discussed previously, the properties of the raw materials, i.e. raw mixes, largely influence the choice of process in general, and the various stages of production. Tables 51 and 52 indicate the most significant relations and functions.

Table 51 Significance of raw mix properties in cement production. (Compare also Table 51 p. 5/3 referring to raw material properties).

Aspects of production	Raw mix properties
Quarrying Crushing Transport Storage Grinding	see Table 40
Slurry preparation	clay mineral content, fineness
Drying	clay mineral content, porosity
Homogenising	chemical and mineralogical variability
Nodulising	clay mineral content
Dewatering	clay mineral, slurry characteristics(filtration)
Burnability	mineralogical composition, fineness, degree of weathering, intergrowth and size of rock fragments
Dust formation	mineralogical composition crystallinity
Coating formation	chemical composition

It becomes obvious that the clay mineral content is of paramount importance form many aspects of production.

Table 52 Summarises the most important raw mix properties influencing the choice of process.

Raw mix properties	Related features	WET PROCESS	DRY PROCESS
moisture content	clay mineral content, porosity	high	low
plasticity, stickiness	clay mineral content	high	low
homogeneity	chemical, physical and mineralogical variability	poor	high
chemical characteristics	chemical composition regarding alkalis,. sulphur, chloride, etc. (contents)	high	low

Table 52 only summarises raw mix aspects. However, other factors, e.g.

- seasonal fluctuations of moisture content
- transport, haulage etc.

are, of course, also determining factors in the choice of process.

4.5 Evaluation of Laboratory Test Results

The steps which are regarded as the final part of a mix design, are preparation, examination and evaluation of test results produced in a laboratory.

4.5.1 Preparation

The proper preparation of laboratory raw mixes for testing is the prerequisite for reliable test results and subsequent evaluation.

It is as important as sampling and it should, therefore, be emphasised that both these processes have to be carried out under observation of strictly defined rules and controls.

4.5.2 Significance of Laboratory Investigations

The characteristics and behaviour of a cement raw material or mix during the various stages of production can never be predicted on the basis of the test results and findings of laboratory investigations alone. Laboratory testing has the disadvantage that many influencing and technologically important parameters such as kiln atmosphere, industrial preparation, etc., can be neither simulated nor reproduced on a laboratory scale. Laboratory produced test results, however, permit the recognition and interpretation of tendencies, whereby a broad variety of individual findings assures a more reliable final evaluation. It is thus recommendable to conduct a series of tests, the results of which can be used to support and control each individual finding. For instance, when the filtration properties of a cement slurry have to be assessed, mineralogical/chemical investigations grain size distribution tests, rheological tests on slurry and specific filtration tests should be conducted rather than a specific filtration test only. The same idea is applicable for all the other assessments of technological properties such as burnability characteristics, grindability properties, etc.

In order to guarantee that the laboratory results correspond as closely as possible to the findings of industrial practice, the design of the laboratory testing methods and other aspects such as limits, reproducibility, etc. should periodically be checked and compared.

4.5.3 Summary of Laboratory Tests

The following tests are available and normally applied in the cement industry (Table 53).

Table 53 Laboratory tests

Material aspects	Test designation	Limits, reproducibility, practice relevance
Stickiness	soil tests	
Burnability	burnability test	tendencies only, but good practice relevance
Grindability	grindability test	quantitative estimate of kWh/t requirements
Volatility of circulating elements	volatility test	quantitative estimate of primary volatility in various atmospheres
Coating behaviour brick selection	coating test	tendencies only, acceptable practice relevance
Filterability	filtration test, testing of slurry rheology	quantitative estimate of key-factors quantitative assessment of rheology
Nodulisability	granulation test, thermo-shock test strength test	tendencies only, practice relevance acceptable

Normally these technological tests are supported by:

- chemical analysis (highly accurate)
- mineralogical analysis (semi-quantitative)
- grain-size analysis (accurate)